An *ex vivo* study of root canal system configuration and morphology of 115 maxillary first premolars

Thomas Gerhard Wolf[1,2*], Christoph Kozaczek[1], Mark Siegrist[3], Madlena Betthäuser[4], Frank Paqué[5], Benjamín Briseño-Marroquín[1,2]

[1] Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Switzerland

[2] Department of Periodontology and Operative Dentistry, University Medical Center of the Johannes Gutenberg-University Mainz, Mainz, Germany

[3] Department for BioMedical Research (DBMR), University of Bern, Bern, Switzerland

[4] Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

[5] Division of Preventive Dentistry, Periodontology, and Cariology, University of Zürich Center of Dental Medicine Zürich, Switzerland

***Corresponding author**

Priv.-Doz. Dr. Thomas Gerhard Wolf

Department of Restorative, Preventive and Pediatric Dentistry

School of Dental Medicine

University of Bern

Freiburgstrasse 7

CH-3010 Bern, Switzerland

e-mail: thomas.wolf@zmk.unibe.ch

Tel: +41 31 632 25 80 (office)

Fax: +41 31 632 98 75 (office)

Keywords

internal morphology; maxillary first premolars; micro-CT; root canal configuration; Swiss-German population

Running title

Morphology of maxillary first premolars by micro-CT

Acknowledgement

The authors deny any conflicts of interest. This study was funded by a research grant of the Swiss Society for Endodontology SSE. We thank Dr. Beat Suter, Prof. Dr. Erik Schulte (Head of Institute of Functional and Clinical Anatomy, University Medical Center of the Johannes Gutenberg-University, Mainz, Germany), Nane Boemke (Head of the cadaver-department and organization of clinical anatomy, Institute for Anatomy, University of Bern, Switzerland) and Michael Stiebritz (Swiss Institute for Translational and Entrepreneurial Medicine in Berne, Dental Research Center) for their kind support.

Statement of clinical significance

Detailed maxillary first premolar root canal morphology information by means of micro-CT of a Swiss-German population is provided in this study. Within the limitations of the study, a clinical recommendation concerning the final physiological foramen preparation size is given.

Abstract

Introduction

The aim of this study was to investigate the root canal system morphology of maxillary first premolars by means of micro-CT in a Swiss-German population.

Methods

The root canal configuration (RCC) of 115 maxillary first premolars (Mx1Ps) were investigated by means of micro-computed tomography CT and 3-D imaging. The RCC and the physiological foramina results are described by a four-digit system code.

Results

12 different RCCs were observed in 30 single-rooted Mx1Ps, being the most frequent ones: 2-2-2/2 (30.0%), 1-2-2/2 (13.3%) and 1-2-1/2 and 2-2-1/2 (10.0%). Seven different RCCs were observed in two-rooted Mx1Ps (n=81), where the: 1-1-1/1 (56.8%), 1-1-1/2 (29.6%) and 1-1-2/2 (8.6%) in the buccal root and 1-1-1/1 (92.6%) and 1-1-1/2 (6.2%) in the palatal root RCCs appeared most frequently. Three-rooted Mx1Ps (n=4) showed a 1-1-1/1 (100.0%) RCC in all roots. The buccal root canal in two-rooted Mx1Ps had one physiological foramen in 59.3%, two in 40.7% and 1-6 accessory foramina in 38.2%. The palatal root canal showed one physiological foramen in 93.8%, two in 6.2% and 1-2 accessory foramina in 14.8%. Single-rooted Mx1Ps showed one physiological foramen in 10.0%, two in 70.0%, three in 13.3%, four in 6.7% and 1-3 accessory foramina in 46.7%.

Conclusions

The results of this study provide detailed morphological RCC information of Mx1Ps in a Swiss-German population. Single rooted Mx1Ps showed morphologic diversifications more frequently than two- or three-rooted Mx1Ps. Within two-rooted

Mx1Ps, the buccal root had a higher RCC variety, accessory canals and foramina number than the palatal root.

Introduction

Precise knowledge of the internal tooth morphology is of utmost importance for a successful endodontic treatment (1). The awareness of the root canal system three-dimensional intricacies substantially facilitates the planning and execution of an endodontic treatment (2-4). An ongoing controversial discussion about the root canal morphology of the maxillary first premolar (Mx1Ps) can be found in literature (2); yet, to the best of our knowledge, there are no micro-CT based studies concerning the root canal system morphology of Mx1Ps. Micro-computed tomography enhanced with 3D imaging is a tooth-structure preserving, noninvasive and replicable research methodology and is regarded to be most suitable for the understanding of root canal systems morphology (5,6). The root canal configuration description suggested by Vertucci (1) is probably the most frequently reported one in the literature. However, the root canal configuration description suggested by Briseño Marroquín et al. (7) describes the root canal pathway in root thirds and physiological foramina number; hence, the present study is aimed to investigate the morphology of 115 Mx1Ps by means of micro-computed tomography with a four-digit code system (7) description as well as an overview of the presence of accessory canals and foramina in an effort to enhance the clinician's endodontic treatment planning and execution decision on the basis of this knowledge.

Materials and Methods

115 extracted human permanent maxillary first premolars were collected for reasons not concerning this investigation from dentists and dental clinics from Berlin and Mainz (Germany) and Bern (Switzerland) and kept in a 3% chloramine solution. The maxillary first premolars (Mx1Ps) were cleaned from calculus or tissue remnants by means of manual and ultrasonic scalers. Only Mx1Ps that could be clearly identified

as Mx1Ps (8) were considered in this study; otherwise they were discarded. Specimens with endodontic treatments, incomplete root development, root fracture, coronal or radicular resorption or root caries were excluded. The Mx1Ps were scanned at an isotropic resolution of 20 µm in a desktop micro-computed tomography unit (µCT 40; Scanco Medical, Brüttisellen, Switzerland) at settings of 70 kV and 114 µA, resulting in 800-1200 slices per tooth. The obtained tooth structure images were visualized and depicted with dummy colors and 3D reconstructions of the micro-computed tomography scans were made by means of a rendering software (VGStudio Max 2.2; Volume Graphics, Heidelberg, Germany) for each tooth. The pulp chamber and the root canal system were color coded with red, the coronal enamel with white, and the dentin with a transparent grayish color. The root canal configuration was described with four digits. The first three digits describe the root canal number at the respective coronal limit of the coronal, middle and apical thirds. The fourth digit (separated with a slash) indicates the number of pertaining physiological foramina (7). Physiological foramina were defined as those pertaining to the same root canal and that had a diameter of no less than 0.1 mm. Furthermore, the number of accessory and connecting canals observed were also investigated. An accessory connecting canal type C describes the communication between two different root canals, also in form of an isthmus. An accessory connecting canal type L resembles a “loop-like” connecting canal that emerges from and returns to the same root canal. The results are expressed through absolute and relative values.

Results

The results showed that out of 115 Mx1Ps, 30 (26.1%), 81 (70%) and 4 (3.5%) were one, two and three-rooted, respectively. The described root canal configurations of the buccal and palatal roots of two-rooted Mx1Ps as well as those with only one and

three roots are shown in Table 1. Single-rooted Mx1Ps had mostly a 2-2-2/2 (30.0%) root canal configuration; another 11 different root canal configurations were observed in single-rooted Mx1Ps ranging from 13.3 to 3.3%. The most frequently observed root canal configuration in two-rooted Mx1Ps in the buccal root was 1-1-1/1 (56.87%); another seven different root canal configurations were observed in this root with an incidence ranging from 29.6 to 1.2%. A 1-1-1/1 (92.6%) root canal configuration was the most frequent one observed in the palatal root. Three-rooted Mx1Ps always showed a 1-1-1/1 (100.0%) configuration (Figs. 1-3).

The results of the physiological and accessory foramina frequency are shown in Table 2. Single-rooted Mx1Ps had one physiological foramen in 10.0%, two in 70.0%, and 1 to 3 accessory foramina in 46.7%. In two-rooted Mx1Ps the buccal canal had one physiological foramen in 59.3%, two in 40.7% and 1 to 6 accessory foramina in 38.2%. The palatal canal had one physiological foramen in 93.8%, two in 6.2% and 1 to 2 accessory foramina in 14.8%. Three-rooted Mx1Ps always showed one physiological foramen in all three roots; no accessory foramina were observed in any of the root canals at all levels.

The results of accessory and connecting canals observed in the coronal, middle and apical root thirds are shown in Table 3. Accessory canals emerging from the buccal root canal could be observed one (13.9%) and four (0.9%) times in the coronal, one (14.8%) and two (2.6%) times in the middle and one (7.8%) and two (3.5%) times in the apical thirds. Accessory canals emerging from the palatal root canal were observed one (2.6%) and two (0.9%) times in the coronal, one (14.8%) and two (1.7%) times in the middle and one (11.3%), two and three (0.9%) times in the apical thirds. One connecting canal type C was the most frequently observed (23.5%), one in the coronal. In the middle third, one type C connecting canal was observed in 10.4%, and one (1.7%) and two (1.7%) type C connecting canals were observed in

the apical third. Connecting canals type L were observed once in 0.9% in the coronal and middle thirds and once (11.3%) and twice (0.9%) in the apical third. In three-rooted first premolars, neither accessory nor connecting canals could be observed in any of the root canals at all levels.

Discussion

The aim of this study was to investigate the root canal system morphology of maxillary first premolars (Mx1Ps) on a sizeable number of specimens by means of micro-computed tomography, allowing a solid statistical evaluation of the results. Different findings of the internal morphology of Mx1Ps have been reported with different *in vivo* and *ex vivo* methodologies (2). Yet, regarding the internal tooth morphology, three-dimensional *ex vivo* investigations are considered to provide more detailed information when compared with *in vivo* methods, such as cone beam computed tomography (9). The information obtained by means of micro-CT allows a less complicated evaluation when compared with other research techniques such as tooth clearing or cone-beam computed tomography (5). It is a noninvasive, reproducible and relatively simple technique that facilitates a quantitative and qualitative analysis of the, unfortunately only *ex vivo*, results (5).

An equivalence summary of the root canal classification system proposed by Briseño Marroquín et al. (7) was established in an effort to be able to compare the results obtained in this study with those of different authors using Vertucci's (1) classification system (Tab. 4). The classification system proposed by Briseño Marroquín et al. (7) describes the root canal configuration individually rather than, as particularly in the case of Mx1Ps, the root canal system in the entire tooth itself; thus, in this study a Vertucci type IV e.g. would be equivalent to a root canal configuration 2-2-2/2 in a single-rooted Mx1P and to a 1-1-1/1 (buccal as well as palatal roots) in two-rooted

Mx1Ps. However, such comparisons should be carefully made, since different authors do not mention if the given configuration was observed in a one-, two- or three-rooted Mx1P.

To the best of our knowledge until now, the root canal morphology of Mx1Ps has not been yet investigated by means of micro-CT. A recent root canal morphology, including Mx1Ps, literature review (2) reports that out of 26 studies the majority of Mx1Ps had in 41.7% one and in 56.6% two roots. These observations are in contrast with our results where one root was observed in 26.1% and two roots in 70.4%. The reason for these discrepancies could be explained by the individual root fusion definition and random teeth selection. In this study, Mx1Ps with fused roots; yet, with two distinct physiological foramina after bifurcating in the middle or apical third of the root were classified as two-rooted Mx1Ps.

Ahmad and Alenezi (2) summarize the results of different research groups being type IV (2-2-2/2; 64.8%) the most frequently reported root canal configuration (RCC), followed by types II (2-2-2/1, 2-2-1/1 and 2-1-1/1; 13.5%) and I (1-1-1/1; 11.4%). However, it should be pointed out that the authors of this review estimated an average of contrasting type IV (2-2-2/2) reported findings ranging from 36.5% (10), 41.7% (11), 64.6% (12), 82.4% (13) to 96.6% (14). All Mx1Ps containing solely one or more root canals with a 1-1-1-/1 RCC were considered together in an effort to establish a correlation with the results of other authors. Thus, a frequency of this RCC of 51.3% was calculated when considering 9, 46 and 4 single, two and three-rooted Mx1Ps. This frequency is then similar to those frequencies reported ranging from 45.7% (15), 51.0% (16) to 52.8% (17). It is necessary to point out that almost always; yet, particularly in the case of the type I (1-1-1/1) RCC, frequencies reported in the literature do not consider the roots individually, but the teeth themselves being relative low as 1.3% (18,19) and 2.1% (13) and similar to the results of this report in

single-rooted Mx1Ps (0.0%). However, contrasting higher results such as 25.1% (17) and 26.2% (11) have also been reported.

A 3.5% frequency observed in the 2-2-2/1 (n=2), 2-2-1/1 (n=1) and 2-1-1/1 (n=1) RCCs (type II) is homogenous with the results reported by Kartal et al. (1.0%) (20) and Ng'ang'a et al. (2.6%) (19); yet, different authors report higher frequencies of this RCC ranging from 29.5% (21), 29.6% (15) to 37.3% (18). A frequency of 29.6% of the 1-1-1/2 RCC, which could also be allocated to Vertucci's type V classification, was the second most common root canal configuration in the buccal root of two-rooted Mx1Ps observed in this study. This high frequency contrasts with other investigations and can be explained through the missing physiological foramina information in all other reports. The less frequent RCCs observed in this study were 1-2-2/2 (13.3%; type V), 1-2-1/2 (type VII) and 2-2-1/2 (10.0%; type VI) and are in agreement with most reports in the literature (1,10-13,15-33) in single-rooted Mx1Ps.

Only 3.5% of the sample included in this research were three-rooted Mx1Ps, which consistently had a 1-1-1/1 (type VIII) RCC. The sample frequency of three-rooted Mx1Ps reported by different authors and ranging from 2.4, 3.3, 3.8 to 4.0% (18,27,33,34) is similar to the ones of this research. However, other authors report relative lower and higher frequencies ranging from 0.5% (11), 1.3% (females) (19) to 11.7% (males) (19). Pineda and Kuttler and Ng'ang'a et al. (11,19) do not report explicitly if the Mx1Ps were three-rooted.

Ahmad and Alenezi (2) report that the majority of Mx1Ps had only one (29.5%) or two physiological foramina (68.6%). Since the RCC classification system employed in this research concentrates on the root individually and not the tooth itself, a direct foramina comparison with other investigations is burdensome. In our results one physiological foramen was observed in 59.3% and 93.8% in the palatal and buccal root canals of two-rooted Mx1PS, respectively and in 10.0% in single-rooted Mx1Ps.

The corresponding one foramen observations reported in the literature range from 13.8% (11), 19.6% (10), 48.4% (15) to 50.1% (22). In this study two physiological foramina was observed in 40.7 and 6.2% (a total of 46.9%) in the buccal and palatal root canals of two-rooted Mx1Ps respectively and in 70.0% of single-rooted Mx1Ps. Although other authors do not report if the Mx1Ps were single or two-rooted, the two physiological foramina results obtained this investigation are similar to the ones obtained by different authors, ranging between 49.4% (11), 50.8% (10). Contrasting corresponding results range from 90.2% (23), 84.5% (22), 79.7% (15), 64.0% (35) to 66.0% (26). Three or more physiological foramina were observed in 5.2% of the Mx1Ps; the corresponding results of other studies could be considered as similar or contrasting and range from 0.5% (11) to 5.0% (1).

Furthermore, Ahmad and Alenezi (2) summarize that 38.0% of the Mx1Ps investigated by different researchers had accessory canals and that 16.0% of them had isthmi. Both single and double-rooted Mx1Ps in this investigation were 42.6 and 33.1% in the buccal and palatal canals, respectively; being relatively close to the one (49.5%) reported by Vertucci (34). Other investigators, without having mentioned if the Mx1Ps had one or two roots, report different accessory canals frequency ranging, according to Ahmad and Alenzi (2), from 78.0% (1) to 19.3% (22). Connecting canals (partly isthmi, type C), between the buccal and palatal canals, were observed in 38.2% of two-rooted Mx1Ps. Similar results have been reported by Caliskan et al. 17.6% (23), Sert and Bayirli 12.0% (31), Kartal et al. 7.0% (20) and Awawdeh et al. 7.0% (22); however, contrasting higher and lower findings from Vertucci 34.2% (34), Rwenyonyi et al. 2.5% (30) and Gupta et al. 16.0% (10) have also been reported.

In spite of the RCCs, physiological foramina or accessory canals, it became evident throughout the discussion that there are similar and contrasting results between the ones here reported and the ones reported in different investigations. Such

differences could be explained by the research sample difference sizes, study methodology and design, sample ethnic origin and differences in age and gender. Regardless of the fact that the authors of this study are of the opinion that age and gender differences are irrelevant when studying the root canal configuration, based on the information obtained in this study, it is not feasible either to support nor to discard this assumption. Yet, the authorsare of the opinion that the most significant cause for such differences lies in the root canal configuration methods employed in the different investigations. As previously mentioned, due to the minute root canal path description of the RCC method employed in this research, there is often a larger or smaller interpretation room when trying to pair it with a different one.

According to the information gained from this study, the clinician should be aware of the morphological complexity of Mx1Ps such as the root canal configuration variety occurrence and of the presence of accessory and connecting canals in any root third of Mx1Ps, which are most of the time not accessible for mechanical root canal preparation. Thus, the application of sufficient root canal irrigating solution and an adequate root canal obturation technique according to the obtained information will play an important role in the success of endodontic surgical and nonsurgical treatment.

Conclusions

- The most frequently encountered RCCs in single-rooted maxillary first premolars are 2-2-2/2 (30.0%), 1-2-2/2 (13.3%), 1-2-1/2 and 2-2-1/2 (10.0%) root canal configurations.
- The most frequently encountered RCCs in two-rooted maxillary first premolars are 1-1-1/1 (56.8%), 1-1-1/2 (29.6%) and 1-1-2/2 (8.6%) in the buccal root, and 1-1-1/1 (92.6%) and 1-1-1/2 (6.2%) in the palatal root.

- Three-rooted maxillary first premolars always showed a 1-1-1/1 root canal configuration (in each root).
- The buccal root canal in two-rooted Mx1Ps showed one physiological foramen in 59.3%, two in 40.7% and 1 to 6 accessory foramina in 38.3%. The palatal root canal showed one physiological foramen in 93.8%, two in 6.2% and 1 to 2 accessory foramina in 14.8%. Single-rooted Mx1Ps showed one physiological foramen in 10.0%, two in 70.0%, three in 13.3%, four in 6.7% and 1 to 3 accessory foramina in 46.7%. Three-rooted Mx1Ps showed only one physiological foramen in all three roots; no accessory foramina were observed in either the palatal- or buccal roots.
- Accessory canals in two-rooted maxillary first premolars emerging from the buccal and palatal root canals were observed in 42.6% and 33.1%, respectively.
- Connecting canals in two-rooted maxillary first premolars between the buccal and palatal root canals were observed in 38.2% of the Mx1Ps examined.

Root		Configuration	Frequency	
			Absolute	Mean
single-rooted		2-2-2/2	9	30.0
		1-2-2/2	4	13.3
		1-2-1/2	3	10.0
		2-2-1/2	3	10.0
		2-2-2/1	2	6.7
		2-1-2/2	2	6.7
		1-2-2/3	2	6.7
		2-2-1/1	1	3.3
		2-2-2/4	1	3.3
		2-2-3/3	1	3.3
		2-1-1/3	1	3.3
		1-2-1/4	1	3.3
two-rooted	buccal	1-1-1/1	46	56.8
		1-1-1/2	24	29.6
		1-1-2/2	7	8.6
		1-2-1/1	1	1.2
		1-2-1/2	1	1.2
		1-2-2/2	1	1.2
		2-1-1/1	1	1.2
	palatal	1-1-1/1	75	92.6
		1-1-1/2	5	6.2
		2-1-1/1	1	1.2
three-rooted		1-1-1/1	4	100.0

Table 1. Root canal configuration of maxillary first premolars by means of micro-CT. The configuration numbers from left to right describe the root canal path from the coronal, middle and apical thirds, respectively (7). The last number, separated with a slash (/), shows the number of physiological foramina observed (B=buccal; P=palatal; n/total=115, n/single-rooted=30, n/two-rooted=81, n/three-rooted=4).

Physiological and accessory foramina frequency														
	1R-Ph		1R-Ac		2R-Ph/B		2R-Ac/B		2R-Ph/P		2R-Ac/Pc		3R	
F	n	%	n	%	n	%	n	%	n	%	n	%	n	%
0			16	53.3			5	61.7			6	85.2		
1	3	10.0	7	23.3	4	59.3	2	29.6	7	93.8	9	11.1	4	100
2	2	70.0	5	16.7	3	40.7	5	6.2	5	6.2	3	3.7		
3	4	13.3	2	6.7			1	1.2						
4	2	6.7												
5														
6							1	1.2						

Table 2. Absolute (n) and mean (%) frequency of the physiological and accessory foramina observed under micro-CT in maxillary first premolars. No accessory foramina were observed in three-rooted maxillary first premolars (F=foramina frequency; 1R=single-rooted, 2R=two-rooted, 3R=three-rooted; B=buccal, P=palatal, Ph=physiological foramina, Ac=accessory; n/total=115, n/one root=30, n/two roots=81, n/three roots=4).

		Accessory canals				Connecting canals			
		B		P		Type C		Type L	
	CC	n	%	n	%	n	%	n	%
Co	0	98	85.2	111	96.5	87	75.7	114	99.1
	1	16	13.9	3	2.6	27	23.5	1	0.9
	2			1	0.9	1	0.9		
	3								
	4	1	0.9						
Mi	0	95	82.6	96	83.5	103	89.6	114	99.1
	1	17	14.8	17	14.8	12	10.4	1	0.9
	2	3	2.6	2	1.7				
	3								
	4								
Ap	0	102	88.7	100	87.0	111	96.5	101	87.8
	1	9	7.8	13	11.3	2	1.7	13	11.3
	2	4	3.5	1	0.9	2	1.7	1	0.9
	3			1	0.9				
	4								

Table 3. Absolute (n) and mean (%) frequency of accessory and connecting canals (type C and L) observed in the coronal (Co), middle (Mi) and apical (Ap) thirds of two-rooted maxillary first premolars under micro-CT. The type C connecting canal communicates between two different root canals, also in the form of an isthmus. The type L connecting canal is a loop-type canal that emerges from and returns to the same root canal (C=canal frequency; B=buccal, P=palatal; n=115).

Vertucci	Briseño Marroquín et al.	%
I	1-1-1/1	0.0
II	2-2-2/1; 2-2-1/1; 2-1-1/1	2.6
III	1-2-1/1; 1-1-2/1	0.0
IV	2-2-2/2	47.8
V	1-1-1/2; 1-1-2/2; 1-2-2/2	3.5
VI	2-1-2/2; 2-2-1/2	4.3
VII	1-2-1/2	2.6
VIII	1-1-1/1 (in all three roots)	3.5

Table 4. Equivalence of the root canal configurations proposed by Vertucci (1) and Briseño Marroquín et al. (7). The mean values express the total ones obtained in this investigation.

Legends

Table 1. Root canal configuration of maxillary first premolars by means of micro-CT. The configuration numbers from left to right describe the root canal path from the coronal, middle and apical thirds, respectively (7). The last number, separated with a slash (/), shows the number of physiological foramina observed (B=buccal; P=palatal; n/total=115, n/single-rooted=30, n/two-rooted=81, n/three-rooted=4).

Table 2. Absolute (n) and mean (%) frequency of the physiological and accessory foramina observed under micro-CT in maxillary first premolars. No accessory foramina were observed in three-rooted maxillary first premolars (F=foramina frequency; 1R=single-rooted, 2R=two-rooted, 3R=three-rooted; B=buccal, P=palatal, Ph=physiological foramina, Ac=accessory; n/total=115, n/one root=30, n/two roots=81, n/three roots=4).

Table 3. Absolute (n) and mean (%) frequency of accessory and connecting canals (type C and L) observed in the coronal (Co), middle (Mi) and apical (Ap) thirds of two-rooted maxillary first premolars under micro-CT. The type C connecting canal communicates between two different root canals, also in the form of an isthmus. The type L connecting canal is a loop-type canal that emerges from and returns to the same root canal (C=canal frequency; B=buccal, P=palatal; n=115).

Table 4. Equivalence of the root canal configurations proposed by Vertucci (1) and Briseño Marroquín et al. (7). The mean values express the total ones obtained in this investigation.

Figure 1. Single-rooted maxillary first premolars. Left: Mx1P with a 2-2-2/2 RCC. Connecting canals (type C) can be clearly observed in the coronal and middle thirds; another one, not as clear, can be observed in the apical third. A loop-connecting canal (type L) can be observed on the buccal root in the limits of the middle and

apical thirds. Right: Mx1P with a 2-1-2/2 RCC. A connecting canal (type C) in the coronal third and three accessory canals in the apical third can be observed.

Figure 2. Two-rooted maxillary first premolars. Left: Mx1p with a 1-1-1/2 (buccal) with multiple accessory canals and a 1-1-1/1 (palatal) with two accessory canals. Right: the buccal and palatal roots of this Mx1P separate below the middle third and depict 1-1-2/2 (buccal) and 1-1-1/1 (palatal) RCCs.

Figure 3. Three-rooted maxillary first premolars. The RCCs in all three-rooted Mx1Ps (two buccals and one palatal) of the sample was always 1-1-1/1 (n=4). An accessory canal can be observed on the palatal root canal of the premolar on the right side.

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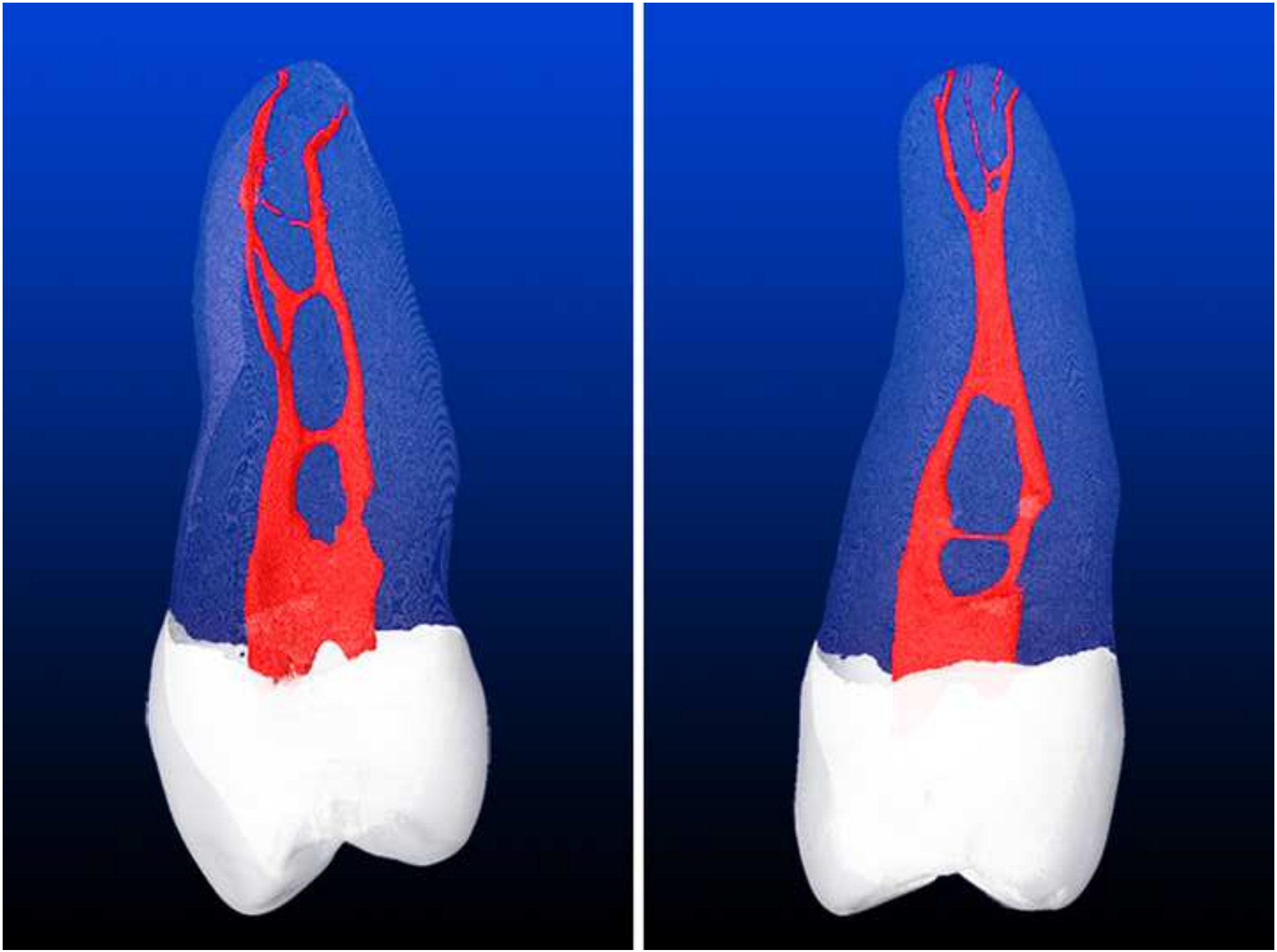

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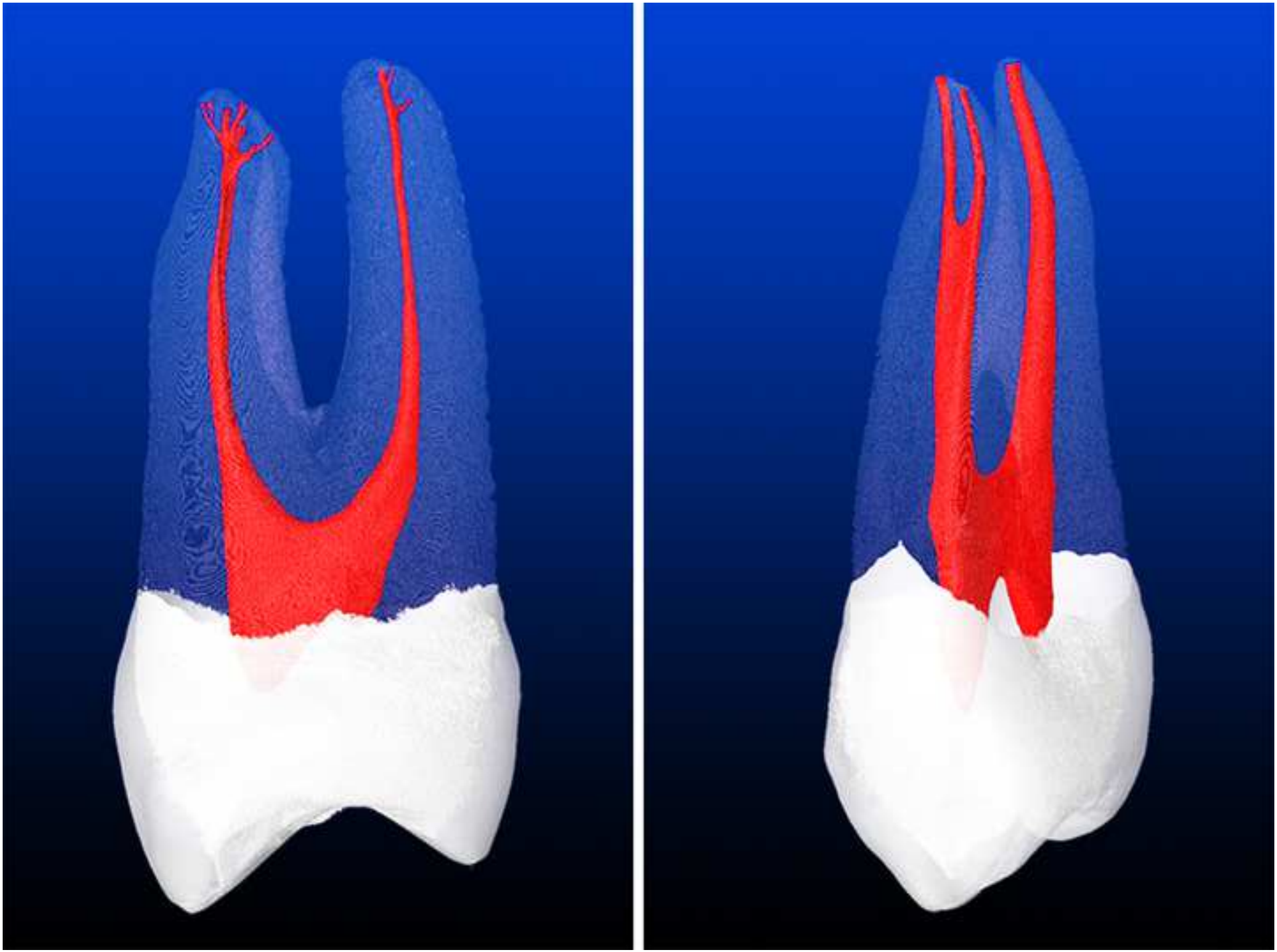

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